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DECLARATION

The undersigned, Dana Scruggs, having an office at 8902B Otis Avenue, Suite 204B, Indianapolis, Indiana 46216, hereby states that she is well acquainted with both the English and German languages and that the attached is a true translation to the best of her knowledge and ability of PCT/EP 2005/051888 (INV.: STEINLECHNER, S.).

The undersigned further declares that the above statement is true; and further, that this statement was made with the knowledge that willful false statements and the like so made are punishable by fine or imprisonment, or both, under Section 1001 of Title 18 of the United States Code and that such willful false statements may jeopardize the validity of the application or document or any patent resulting therefrom.

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Method and Arrangement for Correcting an Angle-Measuring and/or Distance-Measuring Sensor System

Background Information

The present invention relates to a method and an arrangement for correcting an angle-measuring and/or distance-measuring sensor system according to the preamble of the main claim.

Sensor systems designed to measure an angle when a rotating object of measurement is involved, or to measure a distance when a linearly moving object of measurement is involved are already known per se, with which the information to be obtained is represented by a pair of sinusoidal and cosinusoidal measurement signals. The information is usually represented by the amplitude and/or the phase of these measurement signals. The measurement signals often contain angle errors or phase errors, which result from manufacturing tolerances or other circuit-related details in the sensor system.

It is also known per se that sensor systems of this type are designed based on the principle of GMR (GMR = giant magneto resistance) in order to determine the angle of a magnetic field. GMR angular-position sensors of this type ideally output the following signals:

$$x_{ideal} = A \cdot \cos(\alpha)$$

$$y_{ideal} = A \cdot \sin(\alpha)$$

where A = amplitude. These signals are subsequently used to unambiguously determine angle α to be measured. GMR angular-position sensors of this type contain systematic errors, however, and the outputs therefore deliver the following signals:

$$x = A_1 \cdot \cos(\alpha) + x_0$$

$y = A_2 \cdot \sin(\alpha + \delta) + y_0$

Since the variable to be determined is angle α, values x_0 and y_0 are the offsets of the angular-position sensor. Signal amplitudes A_1 and A_2 are usually different, and the phase shift between variables x and y is not exactly 90°; after subtracting the offset and normalizing for the same amplitude, the phase shift has phase error δ.

Publication DE 101 54 153 A1, for example, makes known a method for the offset compensation of an angle-measuring and/or distance-measuring sensor system, with which the values for x_0 and y_0 are determined via measurement, but with which the conditions for amplitudes $A_1=A_2$ and phase error $\delta=0$ must be met.

In addition, a method is made known in DE 100 34 733 A1, with which amplitudes A_1 and A_2, values x_0 and y_0 and phase error δ are calculated from the measurement data. This calculation process is highly complex, so time is critical when it is used as a compensation process. Since the underlying equations are nonlinear in the required parameters, a nonlinear regression must be carried out; iteration and approximation procedures are used, which makes it impossible to calculate the amount of computing time required. The convergence properties of the known methods are highly dependent on whether or not a suitable initial solution has been selected, however. If an unfavorable selection has been made, methods of this type can be disadvantageous.

Advantages of the Invention

The generic method mentioned initially for correcting an angle-measuring and/or distance-measuring sensor system with which sinusoidal and cosinusoidal measurement signals obtained by scanning a moved object of measurement are evaluated and with which the angle errors and/or phase errors of the measurement signals are corrected is advantageously refined by the fact that the method is composed of a compensation process and a subsequent correction process; in the compensation process, offset values of the sinusoidal and cosinusoidal

measurement signals and correction parameters are determined – from a specified number of pairs of measured values obtained by rotating the magnetic field – using the least squares of errors method and solving a linear system of equations. In the correction process, a corrected pair of measured values is subsequently determined out of each pair of measured values, and the angle to be measured is advantageously determined from the particular corrected pairs of measured values using a suitable algorithm.

The pairs of measured values determined in the compensation process according to the present invention are located on ellipses; the parameters of the ellipse are determined using the least squares of errors method. According to an advantageous embodiment, the derivative of the particular square of errors is determined with respect to the parameters of the ellipse, and the particular derivative is set equal to zero, to determine a minimum. The particular derivatives are now used to create the linear system of equations, so that, by using a suitable elimination process, the system of equations is solved for the required parameters of the ellipse and, based on this, the offset values and the correction parameters are determined.

An advantageous system for carrying out a method of this type is also provided, with which the sensor system is installed together with an evaluation circuit for correcting the measured values on an integrated microchip. The microchip with the sensor system and the evaluation circuit preferably includes interfaces for the input and/or output of data and/or parameters. As an advantageous exemplary embodiment, the microchip with the sensor system and the evaluation circuit are used as a steering angle sensor in a motor vehicle.

With the present invention it is therefore easily possible, in a first method part, to analyze the sensor errors of an individual sensor element and determine the associated parameters. In a second method part, the sensor errors can be subsequently corrected and/or compensated for using the evaluation circuit.

The advantage of the proposed means of attaining the object of the present invention is, in particular, that no iterations or approximations are required to

determine the necessary sensor parameters, as is the case with the related art. The result of the evaluation is therefore always available after the same amount of computing time. This is particulary important when the sensor evaluation circuit is adjusted during manufacture, since the steps must be carried out in a fixed production cycle.

Any number of measured values N, e.g., N=100, can be used to calculate the sensor parameters; they are all taken into account according to the principle of the lowest sum of the squares of errors. Furthermore, not all of the parameters that were previously required are determined. Instead, only those parameters are determined that are required to correct the sensor signals, which is only four parameters in this case.

Drawing

An exemplary embodiment of a system for carrying out the method according to the present invention is explained with reference to the drawing.

Figure 1 shows a block diagram of a system of this type for carrying out a compensation process in an angle-measuring and/or distance-measuring sensor system, and

Figure 2 shows a block diagram of the correction process and the determination of the output signal of the angle-measuring and/or distance-measuring sensor system.

Detailed Description of the Exemplary Embodiment

Figure 1 shows a block diagram of a system with which the sinusoidal and cosinusoidal signals x, y provided to measure an angle or distance are processed further by a sensor 1, e.g., an AMR or GMR sensor mentioned in the introduction of the description. Sensor 1 detects the change in the magnetic field of a magnet 2 resulting from an angular displacement α. N pairs of measured values x, y with N, i=1 ...N, e.g., N=100, pairs of

measured values x_i, y_i, are subsequently recorded in a component 4 in a compensation circuit 3. The calculation of parameters explained below is subsequently carried out in a component 5, so that parameters x_0, y_0, m_1, m_2 in this case can be processed further at an output 6 for further evaluation in an evaluation circuit described with reference to Figure 2.

Measured value pairs x_i y_i, which were determined in the compensation process, are located on ellipses and satisfy the following equation, are processed by rotating magnet 2, the magnetic field direction of which is detected in sensor 1:

$$f(x,y) = w_1 \cdot x^2 + 2 \cdot w_2 \cdot x \cdot y + w_3 \cdot y^2 + 2 \cdot w_4 \cdot x + 2 \cdot w_5 \cdot y + 1 = 0 .$$

Parameters $w_1 \ldots w_5$ are the parameters of the ellipse.To determine parameters $w_1 \ldots w_5$ from pairs of measured values x_i, y_i, a least squares of errors method is used to determine square of errors g:

$$g = \sum_{i=1}^{N} f(x_i, y_i)^2 = \min .$$

Square of errors g must be minimized with respect to each of the required parameters of the ellipse $w_1 \ldots w_5$.To do this, the derivative of the square of errors g is taken with respect to each of the parameters of the ellipse $w_1 \ldots w_5$, and the particular derivative is set equal to zero, to determine a minimum:

$$\frac{dg}{dw_j} = 0, j = 1....5 .$$

The results can be used to create a linear system of equations, which can then be solved for the required parameters of the ellipse $w_1 \ldots w_5$, e.g., using Gaussian elimination or another suitable method.

A system of equations of this type can look like this:

$$\begin{bmatrix} sx4 & 2\cdot sx3y & sx2y2 & 2\cdot sx3 & 2\cdot sx2y \\ sx3y & 2\cdot sx2y2 & sxy3 & 2\cdot sx2y & 2\cdot sxy2 \\ sx2y2 & 2\cdot sxy3 & sy4 & 2\cdot sxy2 & 2\cdot sy3 \\ sx3 & 2\cdot sx2y & sxy2 & 2\cdot sx2 & 2\cdot sxy \\ sx2y & 2\cdot sxy3 & sy3 & 2\cdot sxy & 2\cdot sy2 \end{bmatrix} \cdot \begin{bmatrix} w_1 \\ w_2 \\ w_3 \\ w_4 \\ w_5 \end{bmatrix} = \begin{bmatrix} -sx2 \\ -sxy \\ -sy2 \\ -sx \\ -sy \end{bmatrix}$$

The 13 different numerical values required in the system of equations shown above are calculated based on measured data x_i, y_i according to the following relationships:

$$sx = \sum_{i=1}^{N} x_i \qquad sy = \sum_{i=1}^{N} y_i \qquad sxy = \sum_{i=1}^{N} x_i \cdot y_i$$

$$sx2 = \sum_{i=1}^{N} x_i^2 \qquad sy2 = \sum_{i=1}^{N} y_i^2 \qquad sx2y = \sum_{i=1}^{N} x_i^2 \cdot y_i$$

$$sx3 = \sum_{i=1}^{N} x_i^3 \qquad sy3 = \sum_{i=1}^{N} y_i^3 \qquad sxy2 = \sum_{i=1}^{N} x_i \cdot y_i^2$$

$$sx4 = \sum_{i=1}^{N} x_i^4 \qquad sy4 = \sum_{i=1}^{N} y_i^4 \qquad sxy3 = \sum_{i=1}^{N} x_i \cdot y_i^3$$

$$sx3y = \sum_{i=1}^{N} x_i^3 \cdot y_i$$

Using the parameters of the ellipse $w_1 \ldots w_5$ which have been obtained, required offset values x_0, y_0 and parameters m_1 and m_2 described above can now be calculated:

$$x_o = \frac{w_2 \cdot w_5 - w_3 \cdot w_4}{w_1 \cdot w_3 - w_2^2}$$

$$y_o = \frac{w_2 \cdot w_4 - w_1 \cdot w_5}{w_1 \cdot w_3 - w_2^2}$$

To calculate the two parameters m_1 and m_2, we must first calculate intermediate values v and r:

$$v=\sqrt{\frac{w_1+w_3-r}{w_1+w_3+r}} \qquad \text{mit} \qquad r=\sqrt{(w_1-w_3)^2+4\cdot w_2^2}$$

(mit = "where")

Required parameters m_1 and m_2 can now be calculated as follows:

$$m_1=\frac{w_2}{r}\cdot\left(\frac{1}{v}-v\right)$$

$$m_2=\frac{1}{2}\cdot\left(\left(\frac{1}{v}+v\right)-\left(\frac{1}{v}-v\right)\cdot\frac{w_1-w_3}{r}\right).$$

As described with reference to Figure 1, required offset values x_0, y_0 and parameters m_1 and m_2 are subsequently stored at output 6, and corrected pair of measured values x_i', y_i' is determined using the following relationships in a correction component 8 in evaluation circuit 7 shown in Figure 2:

$x_i' = x_i - x_0$ and $y_i' = m_1 \cdot x_i' + m_2 (y_i - y_0)$.

Angle α – which corresponds to the rotation of magnet 2 – to be measured in the system depicted in Figures 1 and 2 can be calculated unambiguously and exactly in a component 9 in evaluation circuit 7 based on the relationship $\alpha = \mathrm{arc}(x' + i \cdot y')$, e.g., using a CORDIC algorithm or an atan2 function known from the C programming language, and it can be provided at an output 10 of evaluation circuit 7.